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GLOBAL DISTRIBUTION OF THE NET ENERGY BALANCE OF THE ATMOSPHERE FROM TIROS RADIATION DATA

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ABSTRACT

A

The radiation data from TIROS II and TIROS III have been analyzed to obtain the monthly averages of the global distribution of the total outgoing radiation from the earth. These data have been combined with climatological estimates of the incoming radiation for the same periods to obtain monthly averages of the regional distribution of the net energy balance. The results show that these data could be useful in studies of the meridional circulation and the evolution of large-scale weather systems.

We have carried out an analysis of the radiation data acquired by the TIROS meteorological satellites, in order to determine the regional and time variations in the energy balance of the earth and its atmosphere.

The energy balance of the earth-atmosphere system is made up of the difference between the incoming solar radiation, mostly in the visible, and the outgoing terrestrial radiation in the infrared. It is well known that the latitude variation of the energy balance shows an excess of incoming solar radiation over outgoing radiation near the equator, and a deficiency at the poles. It is this variation of the energy balance with latitude that drives the atmospheric heat engine. Thus, through the determination of the latitudinal average of the energy balance with the aid of the TIROS data, we obtain the information which is necessary to understand the general circulation of the atmosphere.

At the same time, we have obtained some information regarding the regional variations in the energy balance of the earth-atmosphere system, which give us a very important source of information for the understanding of large scale weather systems.

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Simpson (1929) carried out the first extensive studies of the atmospheric energy balance, by the application of a simplified radiation theory to empirical physical models of the atmosphere. This problem has since been re-examined by Houghton (1954), London (1957), Budyko (1958) and others.

The radiation instrumentation in TIROS, and the physical significance of this experiment, have already been discussed in detail by several authors (Bandeen et al., 1961, Nordberg et al., 1962).

Three of the five channels of the TIROS radiometer measure terrestrial radiation in the far infrared, corresponding to wavelength intervals 5.8 - 6.5 μ, 7 - 13 μ and 7 - 30 μ. The other two channels record the solar radiation reflected by the earth, in the visible spectrum, which gives an estimate of the albedo of any region.

In TIROS II and TIROS III, which were active for five and three months respectively, the channels which measure the reflected visible energy degraded very quickly, and almost no data are available for these channels. It is also possible to obtain information regarding the solar input by the statistical analysis of the TIROS cloud cover photographs (Arking 1964), but this analysis is still in a preliminary stage. Therefore, for this first study of the energy balance, we have used the climatological estimates of Budyko (1958) for the incoming radiation. These give the monthly averages of solar radiation reaching the ground as a function of latitude and longitude, as derived from ground-based pyrohelimeter data.

For the outgoing radiation we have used the TIROS data in the infrared channels. Channel 4, which is sensitive in the 7 - 30 μ interval, and thus records almost 80% of the total outgoing radiation from the earth, also degraded after approximately one month in each of the satellites. The data from Channel 2, sensitive in the 7 - 13 μ interval, however, is available from November 23, 1960, to April 12, 1961, for TIROS II and from July 12 to September 10, 1961 for TIROS III. There was some degradation in this case also, but fairly good estimates of the correction factors for this channel are now available.

Wark et al. (1962) have shown that data from this channel can be used to obtain reasonably good estimates of the total outgoing radiation from the earth. Numerical factors for converting Channel 2 measurements to total outgoing radiation are now available for both TIROS II and III. A comparison between the values of total outgoing radiation derived from Channels 4 and 2 for the overlapping period give satisfactory results.

To obtain an estimate of the temporal as well as regional variations in the total outgoing flux, we have divided the surface of the earth into 10° latitude x 10° longitude intervals between 50° N and 50° S. Because the inclination of the satellite orbit is 48°, the data for polar regions are not available. All measurements made by the satellite in each of these intervals, at nadir angles less than 25°, have been converted to the total outgoing flux and averaged separately for each month. There are approximately 500 observation points per month in each 10 degree square.

The total outgoing flux estimated in this manner is, however, liable to have a small diurnal bias. This is because the orbit of the satellite precesses in right ascension at a rate of 6 degrees per day, or a precession period of 9 weeks. Therefore our results for the total outgoing radiation are affected by the diurnal variation of the ground temperature. However, this effect is small for the particular case of the present study, because we are interested in the long-period averages over large areas. Because of the cloudiness and the presence of water vapor, the average of the channel 2 data over large regions and extended periods of time does not give the ground temperature, but has been shown (Prabhakara and Rasool 1962) to give the effective temperature at a height of ~ 3 km., and therefore the effect of the diurnal variation is much reduced.

As mentioned earlier, for the incoming radiation we have used the climatological estimates of Budyko (1958), which are based on the ground observations of solar radiation , and are given as monthly averages, also in 10 x 10 degree grids. These values were corrected for the absorption of solar radiation by the atmosphere, which, according to London (1957), varies with latitude and season and is ~ 30 to 40% of the radiation which reaches the ground. The energy balance for each $10^{\circ} \times 10^{\circ}$ grid, that is, the difference between these corrected values of incoming energy and the TIROS measured values of the outgoing energy is plotted on a month by month basis in figures 1 through 6. These correspond to the months of December 1960, January, February, March, July and August 1961, respectively. The dark areas correspond to a positive energy balance, i.e., an excess of incoming radiation over the outgoing. The light areas indicate regions of negative balance. In these six figures, the darkest shade (e.g., southwest United States in July) has a value of $> + 1.75 \times 10^5$ ergs/cm^2/sec, while the lightest shade (e.g., $40^\circ - 50^\circ$ N belt in December) corresponds to $< - 1.65 \times 10^5$ ergs/cm^2/sec. The intermediate values of the energy balance are plotted, in steps of $\sim 0.5 \times 10^5$ ergs/cm^2/sec, as seven gradations of the shading level.

The two triangular regions comprising parts of South America and Siberia have been left blank because data from TIROS are not available in those regions. Also the several other $10^\circ \times 10^\circ$ grids left blank in March and July are due to non-availability of data from TIROS for these regions.

A preliminary examination of these figures reveals several interesting features.

(1) In December and January, the regions of maximum positive energy balance are located in the latitudinal belts of $20 - 50^\circ$ S, while in July and August it is the $10 - 40^\circ$ N belt which has a high excess of energy. The evolution of this phenomenon is revealed by the charts for February and March.

(2) The geographical distribution of the energy balance appears to be such that the desert areas of Africa, Australia,

the Middle East and southwestern United States show extreme positive energy inputs in the local summer.

(3) The effect of the monsoon over India is noticeable in comparing the charts for March and August of 1961. The net energy input over India is lower in August than in March, presumably because of the heavy monsoon cloud cover, although if it were not for the monsoon, one would expect a very high excess of energy in the summer month of August.

(4) In the northern hemisphere, the region of the Western Pacific appears to show a relative deficit in energy during all the six months. This area is well known for strong cyclogenic activity. As in the case of the monsoon, the high cloudiness produced by the cyclogenesis probably accounts for the observed low input in energy.

It is hoped that a detailed analysis of these charts, in conjunction with the actually observed global distribution of the weather patterns for the respective months, may provide a better understanding of the role played by the energy balance of the atmosphere in the evolution of weather systems.

In conclusion I should like to thank Professors J. London, R. M. Goody, J. Charney and R. Jastrow for many illuminating discussions, and also Mr. Conrad Hipkins for preparation of the programs by which these data were computed and plotted on the IBM 7094 and the SC 4020.

FIGURES

Fig. 1 through 6: Distribution of net energy balances for the months of (1) December 1960, (2) January 1961, (3) February 1961, (4) March 1961, (5) July 1961, and (6) August 1961. Extreme dark shade $\sim > +1.75 \times 10^5$ ergs/cm^2/sec, and extreme light shade $< -1.65 \times 10^5$ ergs/cm^2/sec.

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December 1960

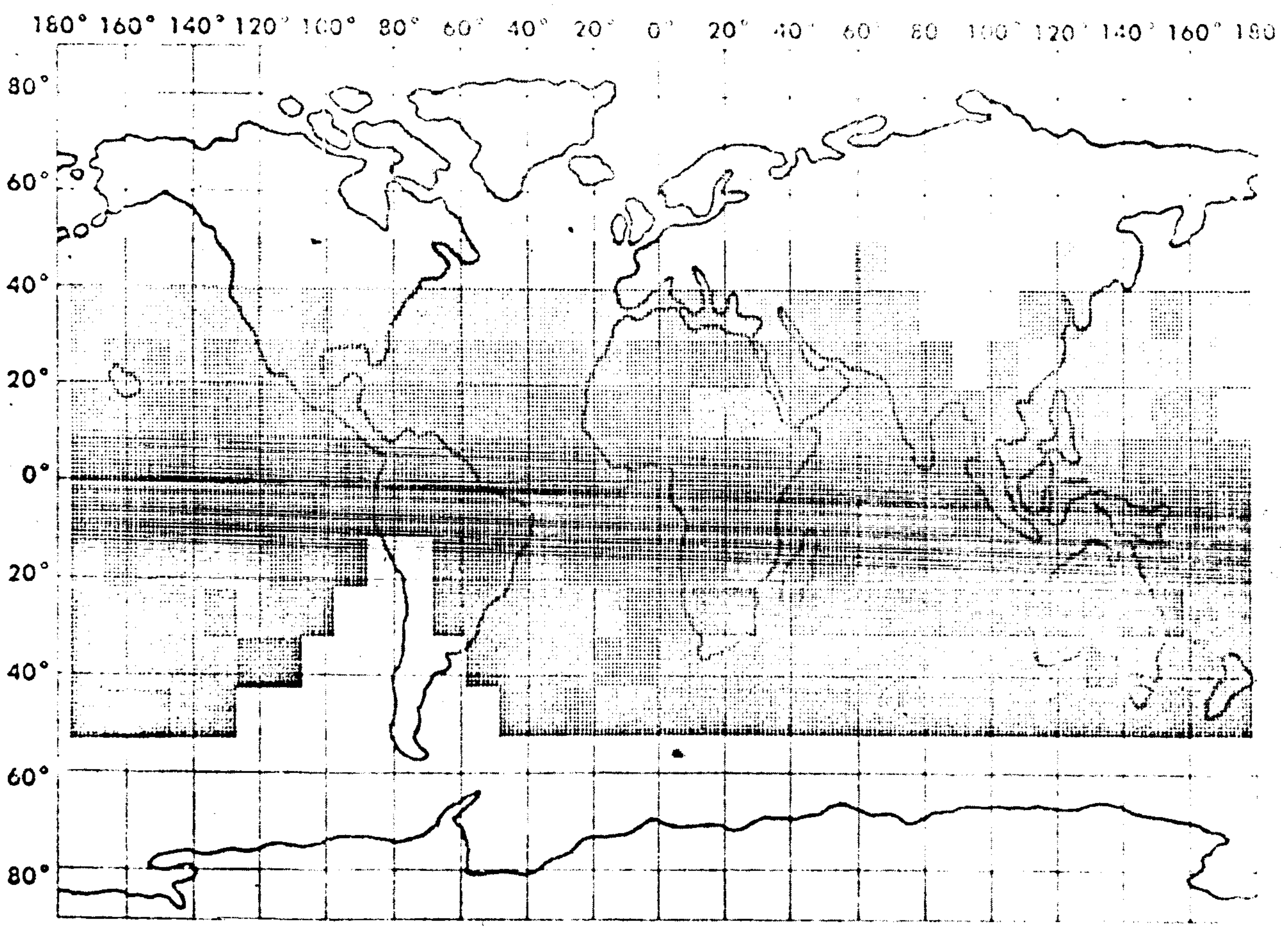

Figure 1

January 1961

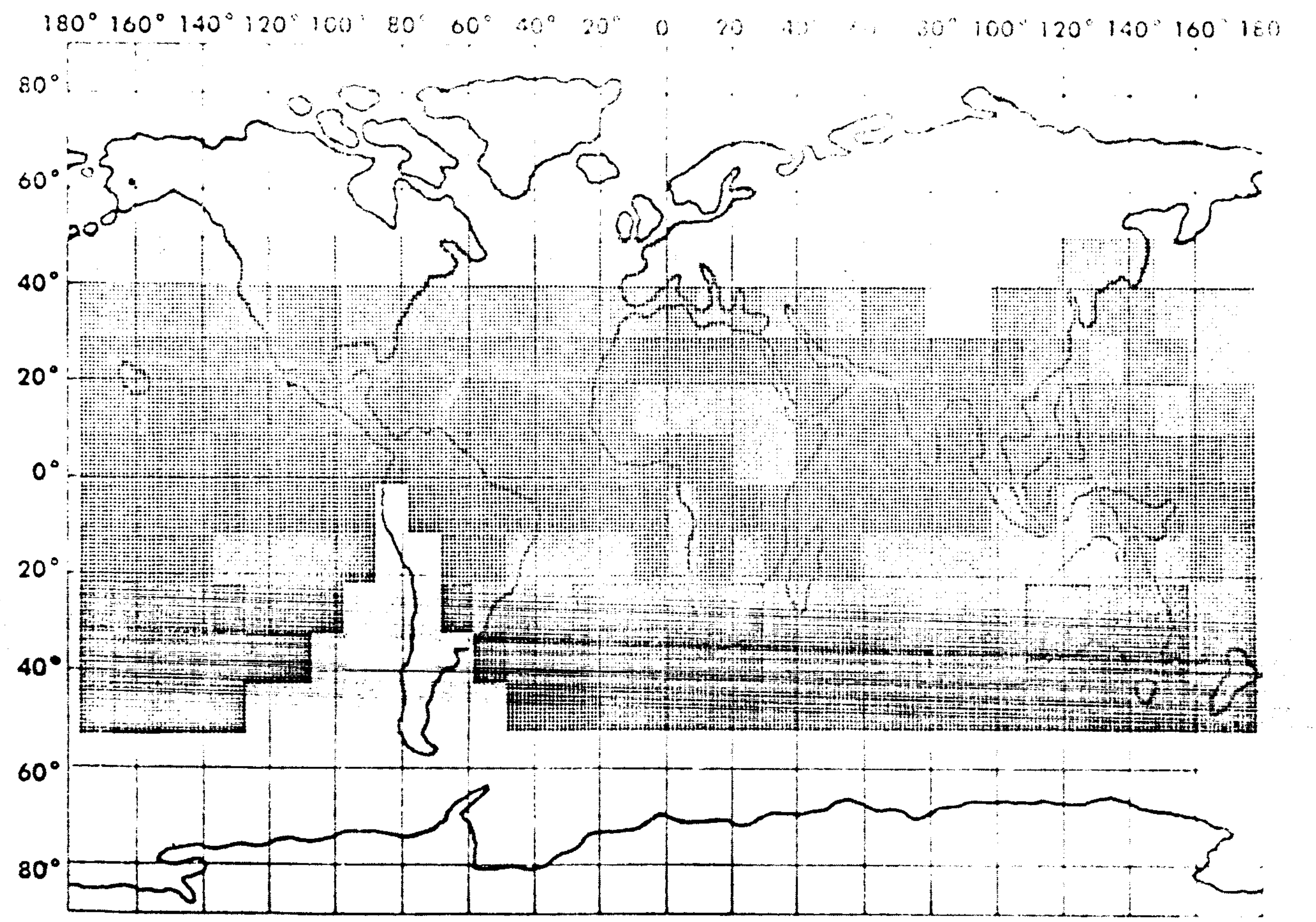

Figure 2

February 1961

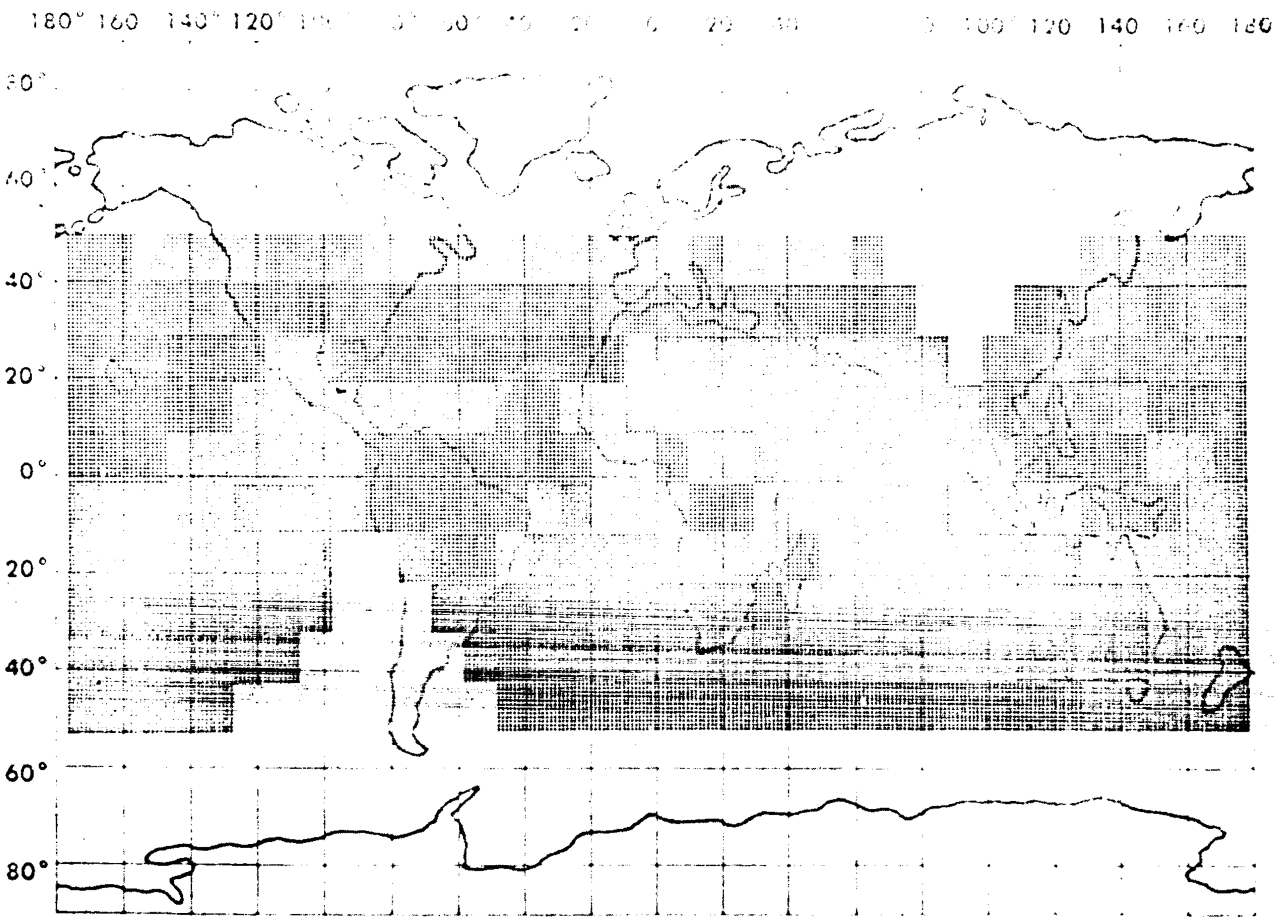

Figure 3

March 1961

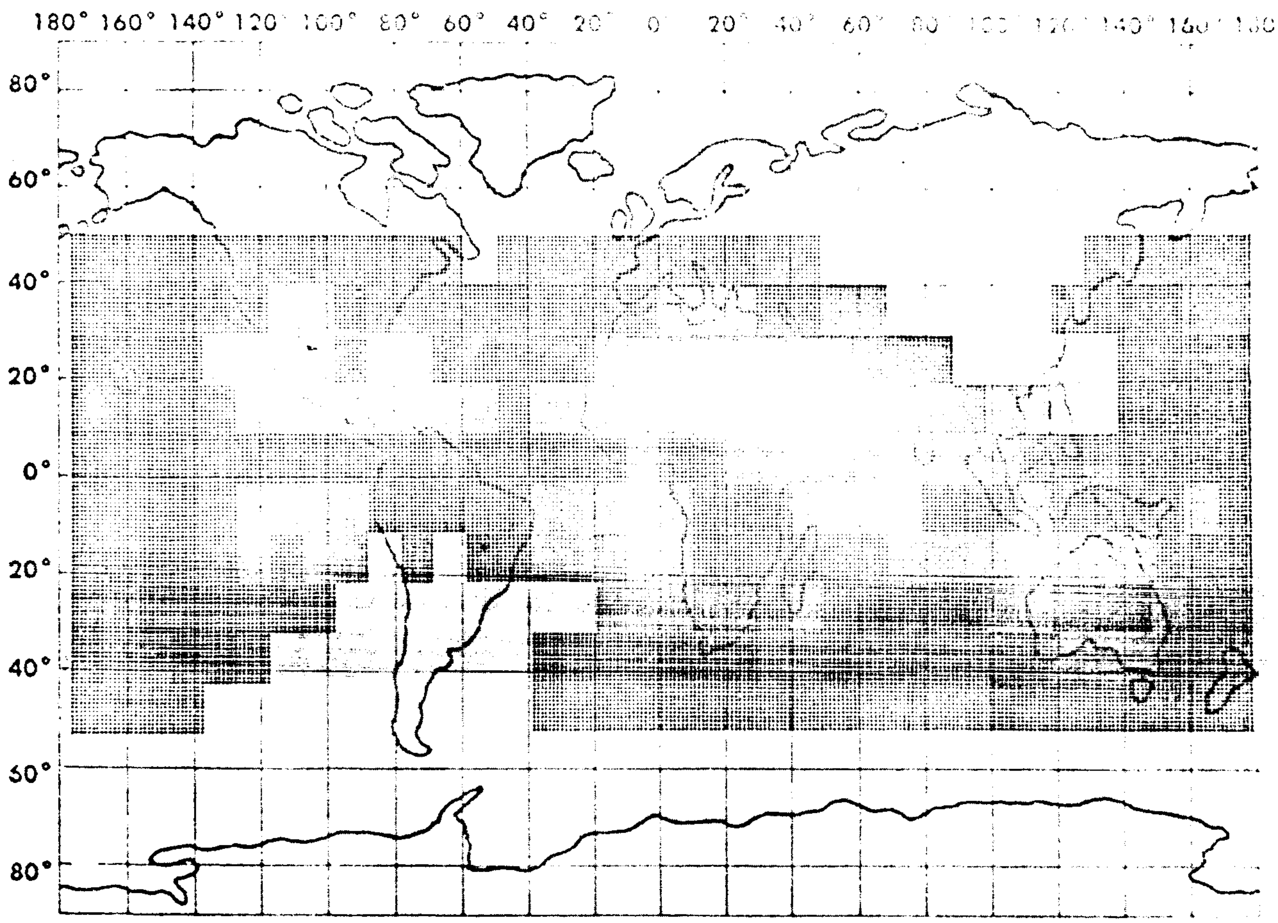

Figure 4

July 1961

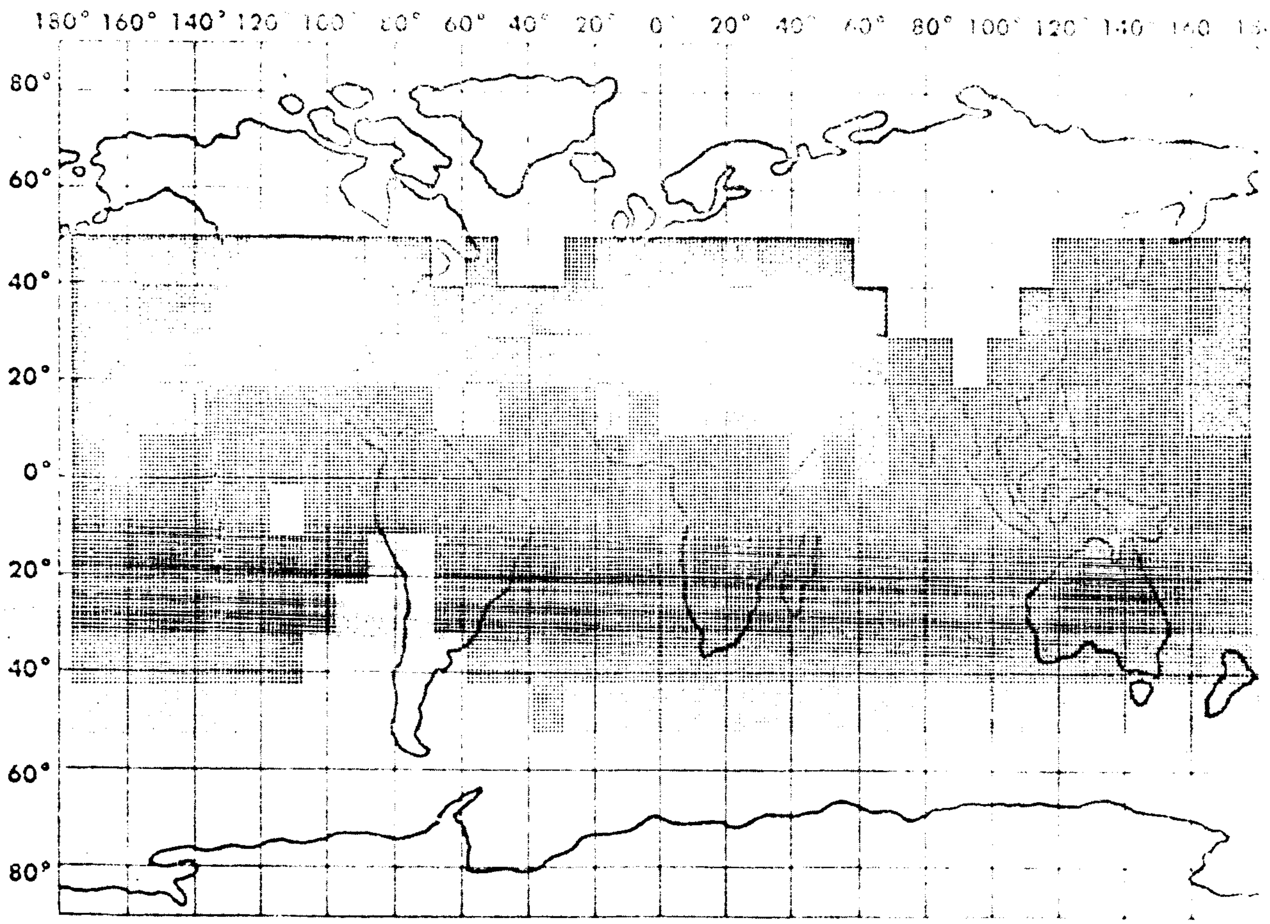

Figure 5

August 1961

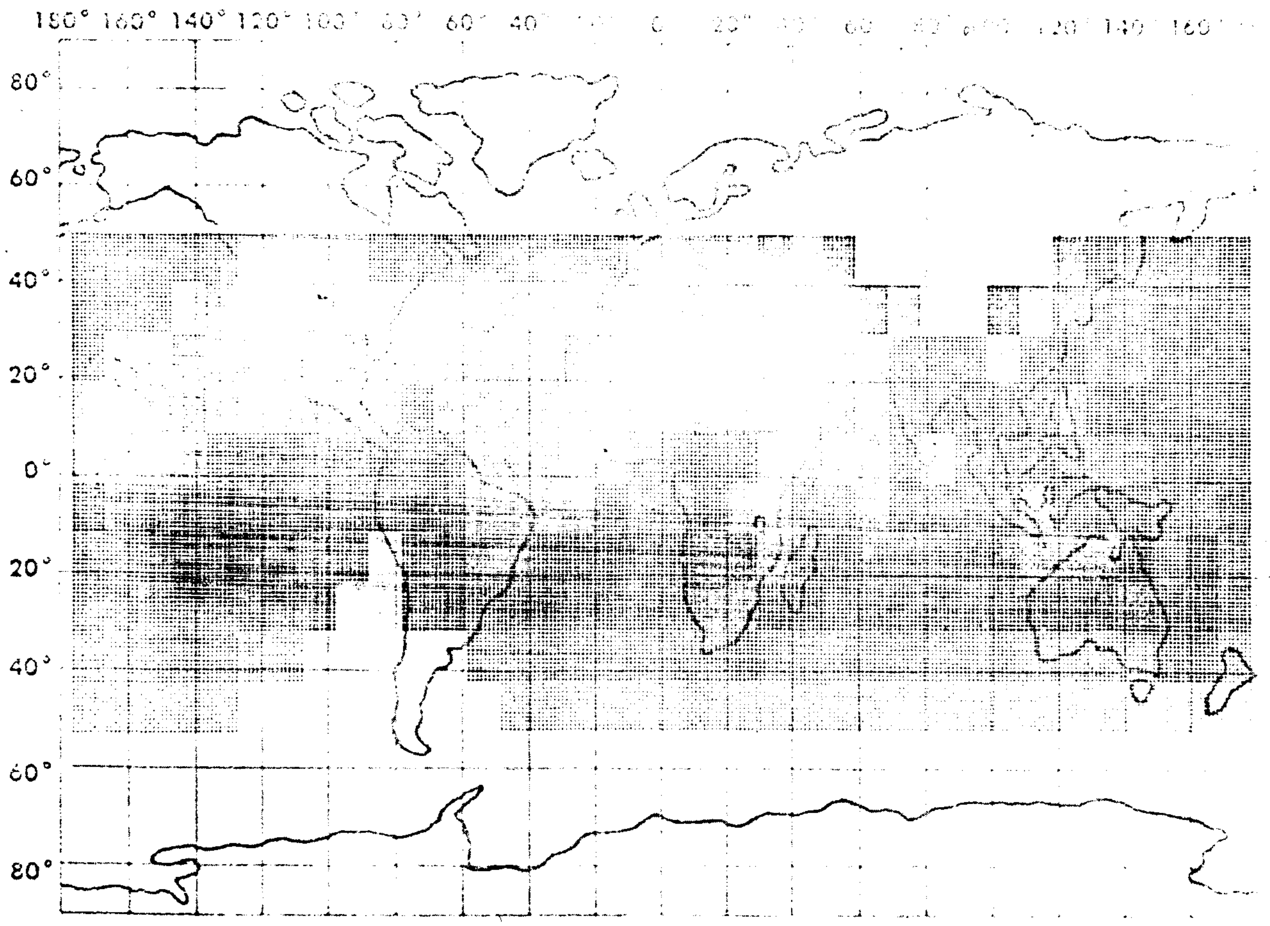

Figure 6